

Reply to comment on “Spatial Coherence and Optical Beam Shifts”

W. Löffler,^{1,*} Andrea Aiello,^{2,3} and J. P. Woerdman¹

¹*Huygens-Kamerlingh Onnes Laboratory, Leiden University,
P.O. Box 9504, 2300 RA Leiden, The Netherlands*

²*Max Planck Institute for the Science of Light,
Günther-Scharowsky-Straße 1/Bldg. 24, 91058 Erlangen, Germany*

³*Institute for Optics, Information and Photonics,
Universität Erlangen-Nürnberg, Staudtstr. 7/B2, 91058 Erlangen, Germany*

In [1], Wang, Zhu and Zubairy repeat their previous claim [2] that the spatial Goos-Hänchen (GH) shift happening at total internal reflection at a dielectric-air interface depends on the spatial coherence of the incident beam. This contradicts our theoretical and experimental findings [3]. Here, we show that the apparent disagreement between their numerical simulations and our results occurs only in a parameter range where the concept of a spatial beam shift is invalid, and that therefore their claim is inapplicable. We clarify this by discussing two key issues.

First, Wang *et al.* observe their effect only if the beam half-opening angle θ_0 is large compared to the difference between the incident angle θ_{inc} and the critical angle θ_{crit} : $|\theta_{inc} - \theta_{crit}| \lesssim \theta_0$. In this case, part of the beam is actually only *partially* reflected, which is in obvious contradiction to the statement in [2] that they aim to investigate the spatial beam shift under *total* internal reflection. The Gaussian Schell Model (GSM) beam half-opening angle θ_S is given by [4]

$$\theta_S^2 = \frac{2}{k^2} \left[\left(\frac{1}{2\sigma_S} \right)^2 + \left(\frac{1}{\sigma_g} \right)^2 \right].$$

For instance, let us consider a case addressed by Wang *et al.* [1] (Fig. 2 therein, envelope waist $\sigma_S = 100 \mu\text{m}$, transverse coherence length $\sigma_g = 6.8 \mu\text{m}$), which we will refer to as “beam A” below. In this case, the half-opening angle is $\theta_S = 1.3^\circ$. If the beam is incident close to the critical angle, about half of the beam is partially reflected (see inset Fig. 1). By definition, this is not a spatial beam shift anymore; a spatial beam shift requires that, upon reflection, the plane-wave components pick up only a phase varying linearly with the angle (see Ref. [5] for an accessible discussion thereof). This becomes obvious by realizing that in the case of Wang *et al.*, the reflected beam is no longer propagation invariant, in fact, part of the beam experiences an *angular* GH shift [6]. This can be seen in Fig. 1, which shows the cross section of the reflected beam A during propagation. We also stress that the beam deformation happening in such a case demands careful treatment of the “beam position”, such as via the centroid or 1st order moment of the intensity distribution; the determination of beam position numerically via the peak position as done by Wang *et al.* [1, 2] is arbitrary.

As a second issue, discussion of beam shifts only

makes sense if the incident and reflected field are actually “beams” according to the paraxial wave equation. This has been worked out by Mandel and Wolf for the case of GSM beams ([4], p. 278 Eq. 5.6-73). As an example, some of the GSM beam parameters used by Wang *et al.* in [2] fulfill the beam condition (e.g., for $\sigma_{gy}/\sigma_y = 0.1$ at $\sigma_y = 50 \mu\text{m}$; σ_y and σ_{gy} correspond to the usual GSM parameters σ_S and σ_g transformed into the interface plane). However, some other clearly violate the beam condition, e.g., for $\sigma_{gy}/\sigma_y = 0.01$. Actually, the field in the latter case would be highly divergent with a half-opening angle $\theta_S \approx 45^\circ$. In this regime (and even more for the case of a “point like source” [1]), reflection at a planar interface requires full vector treatment, which is not provided by the scalar numerical simulations of Wang *et al.* [1, 2]. Basically, in strongly divergent fields, the polarization cross-spectral density function $\hat{\mathbf{W}}$ does not factorize into a polarization and a spatial part anymore, see [7] for a discussion. This is because such strongly focussed beams cannot be homogeneously polarized since transversality of the plane-wave components must be maintained; this is called spin-orbit coupling of light.

We conclude that, as reported in [3], the spatial GH shift of a *bona fide* beam is *not* affected by spatial coherence of the incident beam.

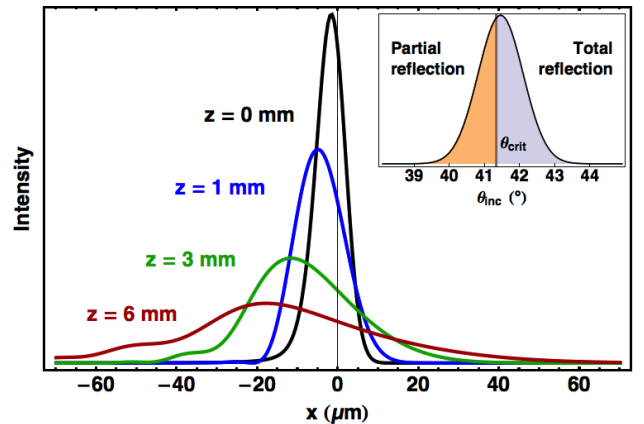


Figure 1. Reflection of the *p*-polarized beam A at around the critical angle ($\theta_{inc} = 41.45^\circ$, $\theta_{crit} = 41.34^\circ$, $\theta_S = 1.3^\circ$) at different propagation distances; the evident beam deformations are due to the mixed spatial-angular character of the shift. Inset: Fourier spectrum of the incident beam.

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